HETEROGENEITY OF INTERMITTENT ENERGY SOURCES AND COST-EFFECTIVE RENEWABLE POLICIES

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Overview

This paper analyzes how cost-effective policies for promoting renewable electricity from wind and solar should be designed in light of their heterogeneous environmental values, i.e. avoided carbon dioxide (CO2) emissions. We compare cost-effective policy designs for different instruments (feed-in tariffs, feed-in premiums, and renewable quotas) using a two-stage model of conventional and renewable electricity supply with endogenous capacity investments and generation dispatch. Using theoretical and numerical partial equilibrium analyses, we find that the gains from differentiating the support mechanism between wind and solar can be considerable and depend on (i) the temporal correlation structure between resource availability and demand, (ii) the non-renewable technology mix, (iii) the price-responsiveness of demand, (iv) the pricing rule for electricity consumers (marginal cost vs. average cost pricing), and (v) the interaction with overlapping carbon regulation.

Context & Method & Results & Contributions to the Literature

Reducing the reliance of today's economic systems on fossil fuels in favor of an increased use of low-carbon and renewable energy sources (RES) will require drastic changes in the future mix of technologies. In many countries, policies to promote investments in RES have largely focused on electricity production from wind and solar energy, using a range of alternative instruments and policy designs—such as, for example, green quotas, feed-in tariffs, production and investment subsidies. A central objective of RES support policies is to reduce carbon dioxide (CO2) emissions at the lowest cost to the public.

Efficiency requires that the marginal cost of emissions reduction be set equal to the marginal damage caused by emissions. If emissions reductions are heterogeneous across RES, efficiency requires that the marginal costs of emissions. abatement should vary across sources according to the degree of emissions caused (Montgomery, 1972; Tietenberg, 2006). Several studies have documented the considerable heterogeneity of intermittent energy sources (wind and solar) in terms of their environmental value, i.e. avoided emissions (Kaffine, McBee and Lieskovsky, 2013; Cullen, 2013; Novan, 2015; Abrell, Kosch and Rausch, 2017). Efficient policies to promote renewable electricity from wind and solar should reflect this heterogeneity. However, the majority of existing and planned regulations are implemented as "undifferentiated" policies, i.e. 1 MWh of electricity generated from different RES is treated homogeneously. Heterogeneity in the environmental value may also adversely interact with overlapping carbon pricing regulation. For example, promoting renewable electricity with a high environmental value under an emissions trading system can lead to a large (unintended) increase in dirty electricity generation due to lowering the equilibrium permit price (Böhringer and Rosendahl, 2010).

This paper investigates how cost-effective policies for promoting renewable electricity should be designed in light of the heterogeneity in the environmental value of wind and solar. We focus on analyzing three different instruments, which have been used in numerous countries to promote investments in wind and solar electricity: feed-in tariffs, feed-in premiums (production subsidies), and renewable quotas (renewable portfolio standards). To analyze the optimal policy design that differentiates between wind and solar to achieve a given carbon abatement target at lowest cost, we formulate a two-stage model of electricity supply of conventional and renewable technologies in which capacity investments and generation dispatch are chosen to maximize economic welfare (producer and consumer surplus) given variable and heterogeneous availabilities of wind and solar.

We identify the drivers and economic conditions for the optimal technology-differentiated policy support, and examine how these affect the gains from differentiation. First, we find that cost-effective policy designs should reflect the temporal availability of RES and their correlation structure with time-varying demand and generation profiles of conventional (non-renewable) energy sources. The pattern and degree of differentiation between wind and solar depends on the composition of the existing energy system before additional RES are added. Second, the price-responsiveness of demand as well as the pricing rule for electricity consumers (marginal cost vs. average cost pricing) influences our results. Third, the optimal policy design is also affected by overlapping carbon regulation where the nature of the policy interaction depends on whether an emissions trading system or a carbon tax is used.

We extend our theoretical analysis to a numerical simluation model of the German electricity market that resolves technology-specific investment and production decisions of profit-maximizing firms. The model captures a number of features at the level of producers and the market that are relevant for studying optimal RES policy design such as, for example, hourly (price-responsive) demand and availability profiles of RES, electricity storage, dynamic cost (ramping constraints), alternative pricing rules for electricity consumers, and carbon regulation. For empirical specification and parametrization of the model, we draw on a detailed data set for the German electricity sector for the year 2014 (including hourly electricity demand and prices as well as hourly generation for wind, solar, and hydropower). We formulate and numerically solve the model as a mixed complementarity problem with primal and dual variables, thus enabling us to formulate the various RES instruments in terms of price- and quantity-based constraints while representing firms' equilibrium behavior and aggregate market constraints.

This paper contributes to the existing literature in several ways. First, recent studies have begun examining the effects of intermittent energy sources for the provision of electricity employing the peak-load pricing model (Crew and Kleindorfer, 1976; Crew, Chitru and Kleindorfer, 1995). Ambec and Crampes (2012) and Helm and Mier (2016) analyze the efficient mix of intermittent renewable and conventional sources and investigate the compatibility of intermittent energy with a decentralized market mechanism. Ambec and Crampes (2015) investigate public policies aimed at promoting intermittent renewable energy sources but do not consider differentiated support policies due to the heterogeneity of RES. Helm and Mier (2016) investigate the market diffusion of intermittent renewables as capacity costs fall. Andor and Voss (2014) investigate optimal promotion policies for RES distinguishing capacity and generation related externalities but consider only one renewable technology. Relative to this literature, we contribute by extending the second (generation dispatch) stage to a multi-period framework. This allows to make to important contributions. First, we determine the impact of the availability profile of renewable energy source on the optimal subsidy rate of different renewable sources. Second, the impact of different pricing rules on the optimal subsidy rates. In electricity markets, consumer often react to yearly average prices and we compare such a pricing scheme against the first-best scheme in which consumers are price responsive in each period.

Second, we add to the literature on the interaction of renewable energy promotion and carbon pricing (Abrell and Weigt, 2008; Böhringer and Rosendahl, 2010; Fischer and Preonas, 2010; Böhringer and Behrens, 2015). A key innovation of this paper here is to examine the implication of availability of intermittent RES for the policy interactions. This enables are more comprehensive appraisal of interactions from overlapping renewable promotion and carbon regulation. Moreover, this strand of the literature does not consider optimal design of RES support policies, and abstracts from detailed features of the electricity system as being portrayed by a technology-rich peak-load pricing model with endogenous investment choice and intermittent RES.

Third, this paper is related to the empirical literature which has gathered empirical evidence about the spatial and temporal heterogeneity of intermittent energy sources (wind and solar) in terms of their environmental value, i.e. avoided emissions (Kaffine, McBee and Lieskovsky, 2013; Cullen, 2013; Novan, 2015; Abrell, Kosch and Rausch, 2017). While these papers generally point out that the heterogeneity of RES may provide a rationale for designing differentiated RES support policies, the exact implications for policy design and the gains from differentiation are not investigated. Similar to this paper, Fell and Linn (2013) investigate the heterogeneity in the market and environmental value of wind and solar power and examine implications for alternative renewable electricity policies. Wibulpolprasert (2016) extends Fell and Linn (2013) by explicitly considering spatial heterogeneity in a model with transmission capacity constraints. Relative to these two papers, we contribute by analyzing optimal RES support policies without and with carbon policy interactions. Moreover, our empirical quantitative analysis provides the first analysis of this kind with a European focus.

The remainder of this paper is organized as follows. Section I presents our theoretical model and results. Section II describes our quantitative framework, including data and computational strategy. Section III presents and discusses our simulation results. Section IV concludes.